"The Elements of Quaternions."

In answer to my reviewer's question (*vide* p. 154), I must frankly admit that

(*a*) Eq. 8, p. 40, should have been a group of six equations, $i = \sqrt{-1}, j = \sqrt{-1}$, &c.; and that

(*b*) The inference should have been that i, j, &c., are (unequal) square roots of negative unity.

H. W. L. Hime.

THE LICK OBSERVATORY.

The recent issue of volumes ii. and iii. of the "Publications" of the Lick Observatory serves to give some indication of the growing activity of this world-famed institution, and to foreshadow the great part which it is destined to play in the astronomy of the future. As in the case of so many other observatory publications, these volumes contain much with which the various astronomical journals have already made us familiar, and one of their chief objects appears to be to collect the observations into a convenient form for reference.

Volume ii. is entirely devoted to the magnificent micrometric work on stars and nebulæ performed by Mr. Burnham during his four years' connection with the Observatory, which, to the general regret, terminated in June 1892. It will be a matter of satisfaction to all interested in the progress of astronomy to learn that this keen-sighted astronomer has nothing but praise for the great telescope. He says: "It has more than satisfied the severest tests which could be applied, and the highest expectations concerning its performance have been realised. It is a monument of the genius and skill of the unrivalled opticians, Alvan Clark and Sons, to whom the progress of astronomical work all over the world is so largely indebted." The fact that powers up to 2600 have been successfully employed, further emphasises the excellence of the objective.

Mr. Burnham strongly insists upon the advantages to be gained by the use of a micrometer in which the wires are bright on a dark field. With this method of illumination, he tells us, "any object that can be seen under any circumstances, however faint, can be well and accurately measured. There is no such thing as a star too faint for measurement, if it can be seen at all."

Besides the immense number of numerical results, the volume gives a mass of most interesting information relating to the various objects observed. Some of this has already been published, but many new points have been added. Thus, it appears that the observations of θ Orionis show that "the six principal stars are absolutely fixed with reference to each other, so far as any change is concerned which could be detected by observations covering more than half a century." The fulness of the account of this remarkable group, and of the numerous supposed discoveries of stars within the trapezium, furnish an excellent example of the thoroughness which is so characteristic of Mr. Burnham's work. With reference to the very faint star discovered within the trapezium by Mr. Alvan E. Clark soon after the telescope was erected, he writes: "It is a difficult object with the 36-inch, and certainly has never been seen before, notwithstanding the numerous alleged discoveries with telescopes down to three or four inches aperture. Not less than a dozen of these imaginary stars have been distributed about the interior of the trapezium."

To the average astronomer, the star 95 Ceti would probably not be of absorbing interest, but to Mr. Burnham it is "the most mysterious and strange double star in the heavens." The companion was discovered by Clark with a 7½-inch, was subsequently measured by Dawes in 1854, and by Burnham with some difficulty in 1888, since when he has not been able to see it even with the 36-inch.

Mr. Burnham finds that "none of the stars which have been supposed from spectroscopic observations to be close doubles, have shown any evidence of the fact when examined with the large telescope under the most favourable conditions." He then goes on to say that "it is possible some other explanation will be found for the recurrent phenomenon first discovered by Miss Maury in the Harvard spectrum photographs. At all events, it is hardly worth while, until the method has been verified upon some of the numerous known pairs suitable for this purpose, to consume the valuable time of the great telescope in a further examination of objects of this class." One would almost imagine that Mr. Burnham had failed to grasp the fact that the separation of the component stars in such cases, by the spectroscopic method, is solely due to their relative velocity, which in ordinary pairs is relatively small. At any rate, it has been estimated that a telescope of sufficient dividing power to separate the components of β Aurigæ must have an aperture, not of three, but of eighty feet!

Limitations of space forbid further reference to the rich feast which Mr. Burnham has provided; the value of much of his work will probably be only fully realised by astronomers of another age, but at the same time a large proportion of his results are of the greatest immediate interest and value.

Vol. iii. of the "Publications" consists of Prof. Weinek's now well-known selenographical studies; a report on specimens of glass similar to those used in the construction of the great object-glass; an investigation of the glass scale of the measuring engine; and Prof. Keeler's observations of the spectra of nebulæ.

It comes as a surprise to us to learn from Prof. Holden's introduction to this volume, that the work of the Lick Observatory is not without danger of suffering for want of funds. Even so small a matter as a suitable instantaneous shutter "could not be constructed until the summer of 1893, for lack of funds and of skilled workmen." In the early stages of the lunar photographic studies, we are also informed that the work would have been seriously interrupted had not the Smithsonian Institution come to the rescue with "several small appropriations of money." The appearance of the present volume has been made possible by the generosity of Mr. Walter W. Law, of New York City, in providing funds to cover the whole cost of producing the fifteen magnificent plates of the moon which embellish its pages. They are modestly described as "a gift to science," and they afford another example of the practical sympathy with astronomical inquiries displayed by so many of our American cousins.

Few will be inclined to deny the great value of the lunar photographs which have been taken at the Lick Observatory, and it is a matter for congratulation that the astronomical world has so soon been made acquainted with the first-fruits of their investigation.

Prof. Holden tells us that it was quite impossible to undertake the investigation of the negatives at the Lick Observatory, owing to the limited staff, and they were therefore placed freely at the disposal of Prof. Weinek, "whose previous experience in lunar observations and in photography, as well as his very unusual artistic skill, made his advice and assistance of extreme value."

No pains have been spared to make the study of the objects selected as complete as possible. As an instance we may mention that Prof. Weinek's drawing of Copernicus, enlarged twenty times from the negative, represents the great labour of 224¾ hours, and is described by Prof. Holden as "a monument of skill and patience."

It is proposed that a complete map of the moon, on a scale of 3 feet to the diameter, shall eventually be made, though the practicability of making a map on four times the scale is demonstrated by an enlargement of Tycho. The photograph of the Lunar Apennines, on the 3-foot scale, reproduced in Fig. 1, is a magnificent example of a camera enlargement from one of the negatives.

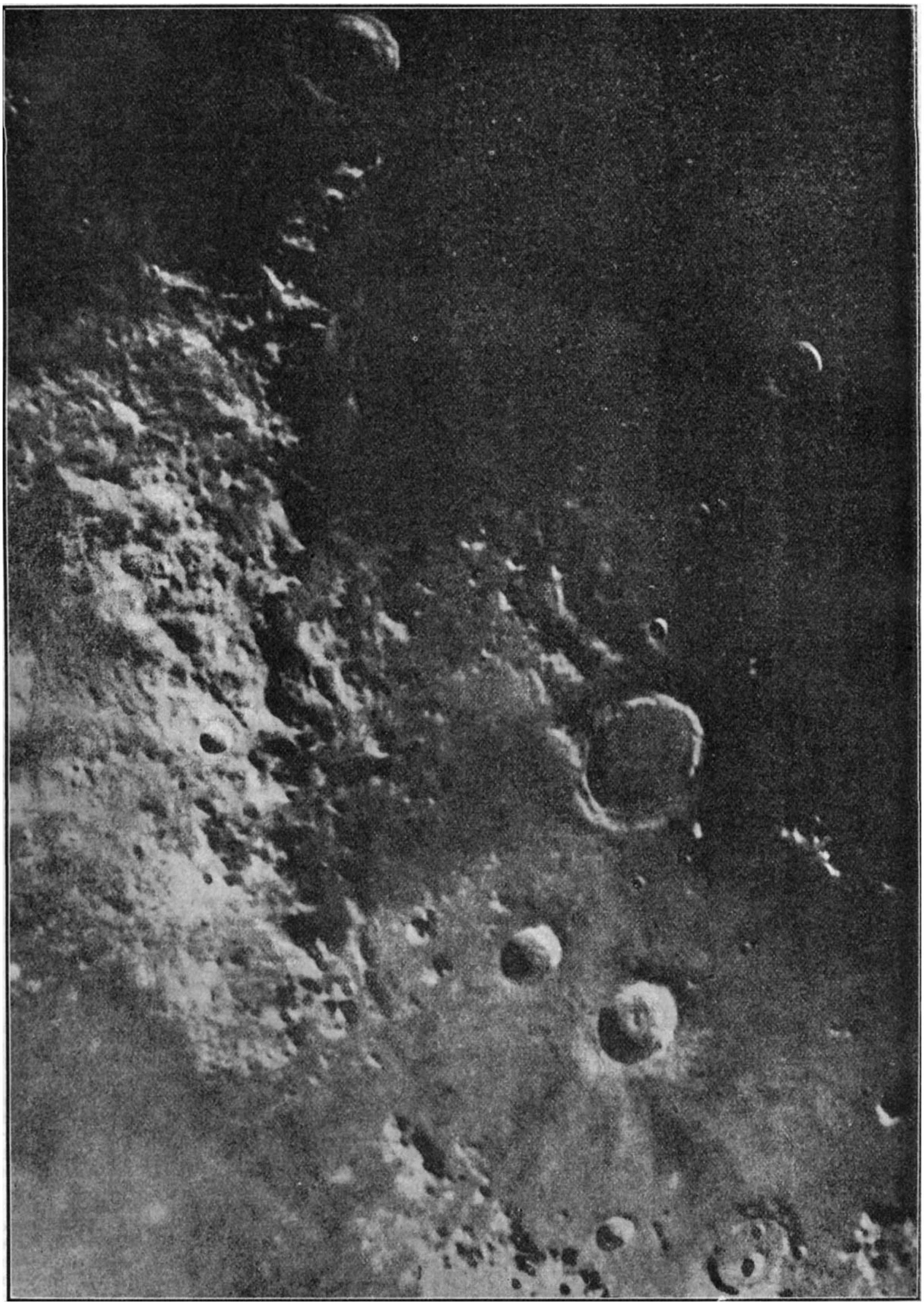

FIG. 1.—The Lunar Apennines, photographed at the Lick Observatory.

Several points of great interest are touched upon by Prof. Holden, among which is a brief discussion of the dimensions of the smallest object on the moon which can be registered on the photographic plate by the 3-foot refractor. From this we learn that a crater on the moon which is less than one-tenth of a mile in diameter will form an image which is about the same size as the grains of silver in the photographic film, and cannot in general be distinguished. Craters not more than 0·3 and 0·15 English miles in diameter, however, have been detected already. Prof. Holden concludes that for further advances in lunar photography it will be necessary to employ plates of greater sensitiveness so as to shorten exposure, and also plates in which the grain is finer. Workers in all departments of celestial photography have felt the need of such improvements, and, as Prof. Holden remarks, "future improvements depend more upon the manufacturer of plates than upon the astronomer who uses them."

Prof. Weinek's concise descriptions of the lunar formations figured in the volume, and his account of the new features so far discovered, leave nothing to be desired. Observers of the lunar surface may take consolation in the fact that even yet they are not in danger of being entirely superseded by photographic methods, for, as Prof. Weinek points out, "both methods must be perfected, and each must support the other." It is worth remark here, however, that enlargements recently made of lunar photographs taken at the Paris Observatory seem to mark a clear step towards perfection. (See page 207.)

Prof. Keeler's work on the spectra of nebulæ during his connection with the Lick Observatory, may fairly be said to mark the commencement of a new era in the history of the spectroscope as an instrument of precision. The observations were undertaken in the first instance at the suggestion of Dr. Huggins, who appealed to the Lick astronomers in 1890 in connection with the discussion as to the origin of the chief nebular line. It was found possible to use the third and fourth order spectra of a grating spectroscope with advantage, and even then the spectra were "by no means extremely feeble." Former work left the wave-lengths of the nebular lines uncertain to at least two tenth-metres, but the uncertainties now amount to only a small fraction of a tenth-metre. Further, it is claimed that the observations of the nebulæ have shown the existence of errors in Angström's scale and in the wave-lengths of the reference lines, so that the observations did not become consistent until more reliable reference wave-lengths were determined by Prof. Rowland. As an example of the accuracy attainable, the velocity of Venus in the line of sight was found to be 6·4 miles per second at a time when the computed velocity was 7·69 miles.

It is not a part of our present purpose to discuss the origin of the chief line in the spectrum of the nebulæ, but we may say that Prof. Keeler does not favour the suggestion that it is due to magnesium; but, on the other hand, his measures definitely decide against the nitrogen origin of the line.

After all corrections have been applied, the normal positions of the first and second lines in the nebular spectrum are stated to be 5007·05 ± 0·03 and 4959·02 ± 0·04 respectively, and neither of the lines is represented among the Fraunhofer lines which appear in Rowland's photographic map. Indeed, we are not aware that either of these lines has ever been recorded as an absorption line in the spectrum of any celestial body whatever.

The observations have not been entirely limited to the determination of the position of the chief line. It has been found, for instance, that "the nebulæ are moving in space with velocities of the same order as those of the stars. Of the nebulæ observed, that having the greatest motion of approach, 40·2 miles per second, is G.C. 4373; that having the greatest motion of recession, 30·1 miles per second, is N.G.C. 6790. Most of the nebulæ have considerably smaller velocities than these."

It might well be imagined by anyone who has seen a photograph of the Orion nebula that the different parts would have a relative movement with regard to each other. Such, however, does not appear to be the case, according to Mr. Keeler; or, at least, there is no relative movement greater than four or five miles per second. Attempts to measure the velocity of rotation of the large planetary nebula G.C. 2102 showed that there was no radial motion greater than eight miles per second.

A study of the spectra of the nuclei of the planetary nebulæ has led Prof. Keeler, as it has independently led Prof. Pickering, to the conclusion that they are very closely connected with the bright-line stars, and thus the latest and most precise work goes to confirm one of the fundamental points of Mr. Lockyer's meteoritic hypothesis.

With reference to the discordant accounts of the spectrum of G.C. 826, to which attention was drawn by myself in 1889 (NATURE, vol. xli. p. 163), it is stated that Dr. Huggins's observation of a continuous spectrum in 1864 "was evidently a mistake," the spectrum being of the usual bright-line type.

Apparently in order to reconcile the presence of a continuous spectrum in such a nebula as that of Orion with the idea that masses of rarefied gas were alone in question, it has been suggested that this continuous spectrum may really be a large number of adjacent bright lines. The enormous dispersion employed by Prof. Keeler, however, fails to resolve it into lines, and thus Prof. Tait's suggestion as to the meteoritic constitution of nebulæ still stands as the best explanation of the spectrum.

Many other points of interest are raised by Prof. Keeler's admirable work, but sufficient has been said to indicate the progress which has been made in this branch of celestial physics and chemistry. Although Prof. Keeler has now removed to the Allegheny Observatory, his successor at the Lick Observatory—Prof. Campbell—has already shown himself to be fully capable of maintaining the spectroscopic department of the Observatory at the same high standard of efficiency.

A. FOWLER.

STUDIES OF A GROWING ATOLL.

THE researches of the surveying ships of the British Navy have from time to time rendered services to science no less important than those which it is their function to perform for navigation. It has become an established practice to encourage the surgeons of these vessels to undertake scientific investigations in the leisure which their professional duties frequently afford, and facilities are sometimes given for a competent man to continue such work by allowing his transference to another vessel when his own has to leave the place where he has been working. For this the Admiralty deserves credit and the thanks of those who desire to see her Majesty's ships maintaining the position they took up in the days of Cook, and continued through the voyage of the *Beagle*, and the long line of expeditions which followed it, to the voyage of the *Challenger*. While it may not be too much to hope for a renewal of special marine research by the Royal Navy before private enterprise reaps the waiting scientific harvest of the unknown Antarctic, we feel that too much prominence cannot be given to the good work done incidentally in the course of routine surveys.

The hydrographer, Captain Wharton, in his preface to the reports of Mr. Bassett-Smith on the Macclesfield